CHAPTER 2

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
FOR THE REMOVAL OF INORGANIC CHEMICAL CONTAMINANTS
BY REVERSE OSMOSIS OR NANOFILTRATION

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, Michigan 48105

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1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN

This document is the NSF Equipment Verification Testing Plan for evaluation of reverse osmosis (RO) or nanofiltration (NF) membrane equipment to be used within the structure provided by the NSF document "Protocol for Equipment Verification Testing of Removal of Inorganic Constituents". This Testing Plan is to be used as a guide in the development of a Field Operations Document (FOD) for testing of RO or NF process equipment to achieve removal of inorganic constituents. It should be noted that this Equipment Verification Plan is only applicable to RO, NF or other high-pressure membrane processes.

In order to participate in the equipment verification process for membrane processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the above-referenced NSF Protocol document as guidelines in the development of a FOD. The FTO shall clearly specify in its FOD the inorganic constituents targeted for removal and the sampling program that shall be followed during Verification Testing. The FOD should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the FOD should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing Program is to achieve removal of inorganic chemical constituents present in feedwater supplies. The Manufacturer may wish to establish a Statement of Performance Capabilities (see General Approach below) that is based upon removal of target inorganic constituent(s) from feedwaters, or alternatively establish one based upon compliance with drinking water standards. For example, the Manufacturer could include in the FOD a Statement of Performance Capabilities that would achieve compliance with maximum contaminant levels stipulated in the National Primary Drinking Water Standards or the EPA National Secondary Drinking Water Regulations for specific water quality parameters (such as fluoride, nitrate, nitrite, cadmium, etc). The experimental design of the FOD shall be developed to address the specific Statement of Performance Capabilities established by the Manufacturer. Each FOD shall include all of the included tasks, Tasks 1 to 5.

2.0 INTRODUCTION

Reverse osmosis, nanofiltration and other demineralization membrane processes are currently in use for a number of water treatment applications ranging from removal of inorganic constituents, total dissolved solids (TDS), total organic carbon (TOC), synthetic organic chemicals (SOCs), and other constituents.

In order to establish appropriate operations conditions such as permeate flux, recovery, cross-flow velocity, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Pretreatment processes ahead of RO or NF systems are generally required to remove particulate material and to ensure provision of high quality water to the membrane systems. For example, RO and NF membranes cannot generally be applied for treatment of surface waters without pretreatment of the feedwater to the membrane system. For surface water applications, appropriate pretreatment primarily for removal of particulate and microbiological species must be applied as specified by the Manufacturer. In the design of the FOD, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the RO or NF membrane process. The stipulated feedwater pretreatment process(es) shall be employed upstream of the membrane process at all times during the Equipment Verification Testing Program. The definition of pretreatment processes shall NOT include scaling control, corrosion control, and treatment for stabilization of RO-treated or NF-treated waters, as these treatments may be considered integral to the operation of the RO or NF systems.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a state or accredited by a third party organization (i.e., NSF) or the U.S. Environmental Protection Agency (USEPA) for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Capabilities the specific performance criteria to be verified and the specific operational conditions under which the verification testing shall be performed. The Statement of Performance Capabilities must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. There are different types of Statements of Performance Capabilities that may be verified in this testing. Examples include two statements shown in Table 1:

For each Statement of Performance Capabilities proposed by the FTO and the Manufacturer in the FOD, the following information shall be provided: percent removal of the targeted inorganic constituent, rate of treated water production (i.e., flux); recovery; feedwater quality regarding pertinent water quality parameters; temperature; concentration of target inorganic constituent; and other pertinent water quality and operational conditions. During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Capabilities.

Table 1: Example Statements of Performance Capabilities for Inorganics Removal

Type of Statement of Performance Capabilities	Example of Statement of Performance Capabilities
Inorganic Removal	*"This package plant is capable of achieving 90% fluoride removal during operation at a flux of 30 gfd (75% recovery; temperature less than 20 °C) in feedwaters with fluoride concentrations less than 10 mg/L and total dissolved solids concentrations less than 500 mg/L."*
Regulatory Compliance	*"This package plant is capable of producing a product water that meets the National Primary Drinking Water Standards for fluoride concentration during operation at a flux of 30 gfd (75% recovery, temperature less than 20 °C) in feedwaters with fluoride concentrations less than 20 mg/L and total dissolved solids concentrations less than 500 mg/L."*

This NSF Equipment Verification Testing Plan is broken down into 5 tasks, as shown in the Overview of Tasks section below. These Tasks shall be performed by any Manufacturer wanting performance verification for their equipment through NSF. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the FOD. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan. All permeate flux values for Verification Testing shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 68 °F or liters per square meter per hour (L/(m^2-hr) at 20 °C. Temperature-correction may also be normalized to 25 °C (77 °F) depending upon the recommendation of the equipment Manufacturer.

4.0 DEFINITION OF OPERATIONAL PARAMETERS

Permeate: Water produced by the RO or NF membrane process.

Feedwater: Water introduced to the membrane element.

Permeate Flux: The average permeate flux is the flow of permeate divided by the surface area of the membrane. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S} \tag{4.1}$$

where: J_t = permeate flux at time t (gfd, L/(h-m^2))
Q_p = permeate flow (gpd, L/h)
S = membrane surface area (ft^2, m^2)

It should be noted that only gfd and L/(h-m^2) shall be considered acceptable units of flux for this testing plan.

Temperature Adjustment for Flux Calculation: Temperature corrections to 20 °C (or 25 °C) for permeate flux and specific flux shall be made to correct for the variation of water viscosity with temperature. The following empirically-derived equation may be used to provide temperature corrections for specific flux calculations:

$$J_t \text{ (at } 20^\circ \text{ C)} = \frac{Q_p \times e^{-0.024 \cdot (T^\circ C - 20^\circ C)}}{S} \qquad (4.2)$$

where: J_t = permeate flux at time t (gfd, L/(h-m^2))
Q_p = permeate flow (gpd, L/h)
S = membrane surface area (ft^2, m^2)
T = temperature of the feedwater (°C)

Net Driving Pressure: The Net Driving Pressure is the pressure available to drive water through the membrane, equal to the average feed pressure (average of feed pressure and concentrate pressure) minus the differential osmotic pressure, minus the permeate pressure:

$$NDP = \left[\frac{(P_f + P_c)}{2}\right] - P_p - \Delta p \qquad (4.3)$$

where: NDP = net driving pressure for solvent transport across the membrane (psi, bar)
P_f = feedwater pressure to the feed side of the membrane (psi, bar)
P_c = concentrate pressure on the concentrate side of the membrane (psi, bar)
P_p = permeate pressure on the treated water side of the membrane (psi, bar)
= osmotic pressure (psi)

Osmotic Pressure Gradient: The term osmotic pressure gradient refers to the difference in osmotic pressure generated across the membrane barrier as a result of different concentrations of dissolved salts. The following equation provides an estimate of the osmotic pressure across the semi-permeable membrane through generic use of the difference in total dissolved solids (TDS) concentrations on either side of the membrane:

$$\Delta p = \left(\left[\frac{(TDS_f + TDS_c)}{2}\right] - TDS_p\right) \cdot \left(\frac{1 psi}{100 \frac{mg}{L}}\right) \qquad (4.4)$$

where: TDS_f = feedwater total dissolved solids (TDS) concentration (mg/L)
TDS_c = concentrate TDS concentration (mg/L)
TDS_p = permeate TDS concentration (mg/L)

Note that the different proportions of monovalent and multivalent ions composing the TDS will influence the actual osmotic pressure, with lower unit pressures resulting from multivalent species. The osmotic pressure ratio of 1 psi per 100 mg/L is based upon TDS largely composed of sodium chloride. In contrast, for TDS composed of multivalent ions, the ratio is closer to 0.5 psi per 100 mg/L TDS.

Specific Flux: The term specific flux is used to refer to permeate flux that has been normalized for the net driving pressure. The equation used for calculation of specific flux is given by the formula provided below. Specific flux is usually discussed with use of flux values that have been temperature-adjusted to 20 °C or 25 °C:

$$J_{tm} = \frac{J_t}{NDP} \qquad (4.5)$$

where: NDP = net driving pressure for solvent transport across the membrane (psi, bar)
J_t = permeate flux at time t (gfd, L/(h-m^2)). Temperature-corrected flux values should be employed.

Water Recovery: The recovery of feedwater as permeate water is given as the ratio of permeate flow to feedwater flow:

$$\%\,\text{System Recovery} = 100 \cdot \left[\frac{Q_p}{Q_f}\right] \qquad (4.6)$$

where: Q_f = feedwater flow to the membrane (gpm, L/h)
Q_p = permeate flow (gpm, L/h)

Recycle Ratio: The recycle ratio represents the ratio of the recycle flow from the membrane concentrate to the total flow of water that is used as feedwater flow to the membrane. This ratio provides an idea of the recirculation pumping that is applied to the membrane system to reduce membrane fouling and specific flux decline.

$$\text{Recycle Ratio} = \left[\frac{Q_r}{Q_f}\right] \qquad (4.7)$$

where: Q_f = total feedwater flow to the membrane (gpm, L/h)
Q_r = recycle hydraulic flow as concentrate to the feed side of the pump (gpm, L/h)

Solute Rejection: Solute rejection is controlled by a number of operational variables that must be reported at the time of water sample collection. Bulk rejection of a targeted inorganic chemical contaminant may be calculated by the following equation.

$$\%\,\text{Solute Rejection} = 100 \cdot \left[\frac{C_f - C_p}{C_f}\right] \qquad (4.8)$$

where: C_f = feedwater concentration of specific constituent (mg/L)
C_p = permeate concentration of specific constituent (mg/L)

Solvent and Solute Mass Balance: Calculation of solvent mass balance shall be performed during Task 1 in order to verify the reliability of flow measurements through the membrane. Calculation of solute mass balance across the membrane system shall be performed as part of Task 3 in order to estimate the concentration of limiting salts at the membrane surface.

$$Q_f = Q_p + Q_c \qquad (4.9)$$

$$Q_f C_f = Q_p C_p + Q_c C_c \qquad (4.10)$$

where: Q_f = feedwater flow to the membrane (gpm, L/h)
Q_p = permeate flow (gpm, L/h)

Q_c = concentrate flow (gpm, L/h)
C_f = feedwater concentration of specific constituent (mg/L)
C_p = permeate concentration of specific constituent (mg/L)
C_f = concentrate concentration of specific constituent (mg/L)

Solubility Product: Calculation of the solubility product of selected sparingly soluble salts will be important exercise for the test plan in order to determine if there are operational limitations caused by the accumulation of limiting salts at the membrane surface. Text book equilibrium values of the solubility product should be compared with solubility values calculated from the results of experimental Verification Testing, as determined from use of the following equation:

$$K_{sp} = \gamma_A^x \left[A^{y-}\right]^x \gamma_B^y \left[B^{x+}\right]^y \qquad (4.11)$$

where: K_{sp} = solubility product for the limiting salt being considered
γ = free ion activity coefficient for the ion considered (i.e., A or B)
[A] = molal solution concentration of the anion A for sparingly soluble salt A_xB_y
[B] = solution concentration of the anion B
x, y = stiochiometric coefficients for the precipitation reaction of A and B

Mean Activity Coefficient: The mean activity coefficients for each of the salt constituents may be estimated for the concentrated solutions as a function of the ionic strength:

$$\log \gamma_{A,B} = -0.509 \cdot Z_A Z_B \sqrt{\mu} \qquad (4.12)$$

where: γ = free ion activity coefficient for the ion considered (i.e., A or B)
Z_A = ion charge of anion A
Z_B = ion charge of cation B
μ = ionic strength

Ionic Strength: A simple approximation of the ionic strength can calculated based upon the concentration of the total dissolved solids in the feedwater stream:

$$\mu = (2.5 \cdot 10^{-5}) \cdot (TDS) \qquad (4.13)$$

where: μ = ionic strength
TDS = total dissolved solids concentration (mg/L)

5.0 OVERVIEW OF TASKS

The following section provides a brief overview of the tasks that shall be included as components of the Verification Testing Plan and FOD for removal of inorganic chemical contaminants.

5.1 Task 1: Membrane Operation

The objective of this task is to evaluate RO or NF membrane operation. The system performance shall be evaluated relative to the stated water quality goals and other performance characteristics specified by the Manufacturer. For Verification Testing purposes, the equipment shall be operated for a minimum of one, one-month testing period (see Testing Periods section below). Membrane productivity, rate of specific flux decline, and rejection capabilities will be evaluated at one set of operating conditions for the testing period. Membrane operations performance will also be evaluated in relation to feedwater quality and changes in quality resulting from seasonal or climatic changes. The impact of scale formation on specific flux may also be evaluated via addition of different pretreatment chemicals.

5.2 Task 2: Cleaning efficiency

An important aspect of membrane operation is the restoration of membrane productivity after specific flux decline has occurred. The objective of this task is to evaluate the efficiency of the membrane cleaning procedures recommended by the Manufacturer. At the conclusion of the required one-month testing period, the membrane system will be cleaned chemically according to the Manufacturer's recommended procedures. The fraction of specific flux that is restored following chemical cleaning will be determined and recorded.

5.3 Task 3: Finished water quality

The objective of this task is to evaluate the quality of water produced by the membrane system and the removal of inorganic chemical contaminants achieved by the membrane system at the specified operational conditions. Multiple water quality parameters will be monitored during the one-month testing period, as specified by the FTO on behalf of the Manufacturer in the FOD. At a minimum, monitoring of the water quality parameters shall include the following: pH, feedwater temperature, conductivity, total dissolved solids (TDS), alkalinity, Langlier Saturation Index (LSI), turbidity, total suspended solids (TSS), silica (total & dissolved), total organic carbon (TOC) and silt density index (SDI). Other water quality parameters that may include individual inorganic chemical contaminant concentrations will be selected and included in the FOD at the discretion of the FTO and the Manufacturer. Water quality produced will be evaluated in relation to feedwater quality and operational conditions. Mass balances for selected inorganic constituents shall be calculated as needed to determine the accumulation of limiting salts on the membrane surface. Post-treatment capabilities of the package equipment shall also be evaluated for pH adjustment, corrosion control, removal of carbon dioxide and hydrogen sulfide (if present) from the permeate stream.

An overview of the equipment operational and production characteristics to be evaluated for each task of the Verification Testing Plan is provided in Table 2.

5.4 Task 4: Data Handling Protocol

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the FTO and the NSF during Verification Testing. Prior to the beginning of field testing, the database or spreadsheet design must be developed by the FTO and reviewed and approved by NSF. This will insure that the required data will be collected during the testing, and that results can be effectively transmitted to NSF for review. Relevant data will be prepared for inclusion in a final report at the conclusion of the Verification Testing Program.

Table 2: Summary of Equipment Operational Characteristics to be Evaluated in Each Verification Testing Task

Type of Statement of Performance Capabilities (See Table 1)	Equipment Operational Characteristic to be Evaluated	Task
Inorganic Removal	1. Feedwater flow rate	1
	2. Permeate flow rate	1
	3. Concentrate flow rate	1
	4. Inlet and Outlet pressures to membrane element	1
	5. Permeate pressure	1
	6. Feedwater temperature	1
	7. Recycle Ratio	1
	8. Power consumption	1
	9. Permeate stream characterization	3
	10. Calculation of limiting salt concentrations	3
	11. Waste stream characterization and range of waste stream flow rates	1,3
Regulatory Compliance	Characteristics 1 through 11, and:	
	12. Comparison of target inorganic constituents concentration to National Primary Drinking Water Standards and Secondary Drinking Water Standards	3

5.5 Task 5: Quality Assurance Project Plan

An important aspect of Verification Testing is the Quality Assurance Project Plan (QAPP) developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during membrane equipment Verification Testing.

6.0 TESTING PERIODS

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 5) are designed to be completed during the one-month testing period, not including mobilization, shakedown and start-up. The Verification Testing Program requires that one testing period be performed for Verification Testing; however, it is recommended that additional testing periods be conducted in order to verify equipment performance under different conditions of feedwater quality and temperature. The schedule for equipment monitoring during the one-month testing period shall be stipulated by the FTO in the FOD, and shall meet or exceed the minimum monitoring requirements included under Task 1 of this testing plan. The FTO shall ensure in the FOD that sufficient water quality data and operational data will be collected to allow estimation of statistical uncertainty in the Verification Testing data, as described in the "Protocol for Equipment

Verification Testing of for Removal of Inorganic Constituents”, Section 4.5. The FTO shall therefore ensure that sufficient water quality and operational data are collected during Verification Testing for the statistical analysis described herein.

The recommendation for Verification Testing beyond the required one-month testing period is based on evaluation of equipment performance under different feedwater quality conditions that may be experienced annually. For example, climatic changes between rainy and dry seasons may produce substantial variability in feedwater turbidity and TOC for surface water sources. In addition, seasonal changes may also affect groundwater source quality by introducing variability in feedwater pH and variations in concentrations of TDS and specific inorganic chemical constituents. Cold weather operations can be an important component of seasonal water quality testing because of the impact of cold temperatures (1 °C to 5 °C) on water viscosity, membrane permeability and diffusional processes. In particular, for membrane process treatment equipment, factors that can influence treatment performance include:

- feedwaters with high seasonal concentrations of inorganic constituents and TDS. These conditions may increase finished water concentrations of inorganic chemical contaminants and may promote precipitation of inorganic materials in the membrane;
- feedwaters with variable pH; increases in feedwater pH may increase the tendency for precipitation of sparingly soluble salts in the membrane element and may require variable strategies in anti-scalant addition and pH adjustment;
- cold water, encountered in winter or at high altitude locations;
- high concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasons;
- high turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single one-month period. Therefore, additional testing beyond the required one month of testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During each testing period, Tasks 2 and 3 (evaluation of cleaning efficiency and finished water quality) can be performed concurrent with Task 1, the membrane operation testing procedures.

7.0 TASK 1: MEMBRANE OPERATION

7.1 Introduction

Membrane operation will be evaluated in Task 1, with quantification of temperature-corrected rate of specific flux decline and water recoveries. The rates of specific flux decline will be used to demonstrate membrane performance at the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the FTO in terms of a temperature-corrected flux value (e.g., gfd at 68 °F or L/[m^2-hr] at 20 °C) before the initiation of the Verification Testing Program.

Monitoring in Task 1 shall be focused on determination of the operational characteristics such as those indicated in Table 3 (e.g.: flux, temperature-corrected specific flux, recovery, etc.). The actual operational parameters monitored will depend upon the type of Statement of Performance Capabilities made in the FOD, or other factors applicable to the technology which provide effective treatment of the feedwater. The FTO shall establish the testing conditions to be evaluated for Task 1 in the FOD. An NSF field inspection of equipment operations and sampling and field analysis procedures may be carried out during the initial test runs in Task 1.

Rate of temperature-corrected specific flux decline is a function of water quality and operational strategy. Many additional factors may influence specific flux decline with RO or NF membranes including membrane compaction, inorganic scaling, particulate or organic fouling, biofouling, and other factors. In this task, specific flux decline shall be monitored to evaluate operational trends. Chemical characterization of the feedwaters and permeate water stream with calculation of membrane rejection capabilities will be performed as part of Task 3. In addition, calculation of the operational limitations caused by limiting salt concentrations will be performed in Task 3. The testing runs conducted under Task 1 shall be performed in conjunction with Tasks 2 and 3. With the exception of the additional testing periods conducted at the FTO's discretion, no additional membrane test runs are required for performance of Tasks 2 and 3.

Any pretreatment included in an RO, NF or other treatment system designed for inorganic contaminant removal shall be considered to be an integral part of the package membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes. The definition of pretreatment processes shall NOT include scaling control, corrosion control, and treatment for stabilization of RO-treated or NF-treated waters, as these treatments may be considered integral to the operation of the RO or NF systems.

7.2 Experimental Objectives

The objectives of Task 1 are to demonstrate the following: 1) the appropriate operational conditions for the membrane equipment; 2) the feedwater recovery achieved by the membrane equipment at the designated operational conditions; and 3) the rate of specific flux decline observed over extended membrane filtration operation during the one-month testing period. This task is also intended to provide in operational power consumption information that can be used to develop cost estimates for operation and maintenance of the equipment. Complete chemical and physical characterization of the feedwaters and treated waters produced by the system, with calculation of limiting salt concentrations, will be performed as part of Task 3.

It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the FTO, as pertains to permeate flux and transmembrane pressure. Verification of membrane operation under the conditions specified in the Statement of Performance Capabilities shall also apply to conditions that are considered less challenging to the RO or NF system. Examples of conditions considered less challenging may include lower permeate fluxes, lower system recoveries and higher cross-flow velocities.

7.3 Work Plan

Mobilization and start-up of equipment shall be performed prior to the initiation of Task 1 testing. Furthermore, the RO or NF membrane treatment system shall have achieved a condition of steady-state operation prior to the start of Task 1 testing. The FTO shall clearly describe in the FOD the protocol for start-up of the membrane system, as well as operations and maintenance issues that may arise during mobilization and start-up.

After set-up and shakedown of the membrane equipment, RO or NF operation should be established at the operational conditions established by the Statement of Performance Capabilities. The membrane system shall be operated as shown schematically in Figure 1 for a minimum of one month. A summary of the operational parameters to be recorded during Task 1 and the minimum frequency of monitoring are presented in Table 3. The FTO shall provide in the FOD the necessary methods for monitoring of the operational parameters presented in Table 3. Additional monitoring of feedwater chemistry shall be performed during Verification Testing, as described below in Table 3.

Table 3: Task 1 Required Minimum Operating Data

Operational Parameter	Action, Monitoring Frequency
Feedwater, permeate and concentrate flow rates (for each stage of the RO or NF system)	Check and record twice daily. Adjust when 10% above or below target. Record both before and after adjustment.
Membrane Element Inlet and Outlet Pressures (for each stage of the RO or NF system)	Check and record twice daily.
Permeate Pressure (for each stage of the RO or NF system)	Check and record twice daily
Recovery (for each stage of the RO or NF system)	Check and record twice daily. Adjust when 10% above or below target.
Recycle Ratio	Check and record twice daily. Adjust when 10% above or below target.
Total Dissolved Solids Concentration in Feedwater, Concentrate, Permeate (for each stage of the RO or NF system)	Calculation of osmotic pressure gradient on daily basis. (Calculation per Eqn. 4.4, Section 4).
Feedwater Temperature	Record twice daily
Horsepower and efficiency of motors, and consumed amperage for RO or NF treatment (at each set of operational conditions)	Provide record of pumping requirements, current draw to motors on cumulative basis, power factor.
Concentrate composition for disposal	Sample waste stream once during the minimum one-month testing period.
Concentrate flow rate for disposal	Check and record waste flow streams (if applicable) twice daily.

Determination of optimal membrane operating conditions for a particular water could potentially require as long as one year of operation. For Task 1 however, each set of operating conditions shall be maintained for the one-month testing period (continuous 24-hour operation). At a minimum, the membrane shall be chemically cleaned according to Manufacturer's specifications at the conclusion of the one-month testing period. At this time, the cleaning efficiency shall be determined per the requirements outlined in Task 2.

If substantial specific flux decline occurs at the specified operating conditions before the one-month operating period is complete, adjustments to the operational strategy shall be made (such as a decrease in nominal flux or recovery). Decisions on which adjustments should be made shall be based upon the Manufacturer's experience and consultation with the FTO conducting the study. Adjustments in chemical addition (such as anti-scalant addition and pH adjustment) shall not be considered to constitute changes in the overall operational strategy, as mentioned above. The FTO shall also specify the run termination criteria for the particular RO or NF membrane equipment being tested under the Verification Testing Program. For example, the termination criteria may be defined as a 10% or 20% decline in specific flux, a drop in the percent solute rejection, or an increase in transmembrane pressure to a specific value. In the case that fouling and specific flux decline occurs in a shorter time than the one-month testing period, the membrane shall be chemically cleaned and the operating or pretreatment conditions shall be adjusted. After these conditions are changed, the system would be operated until the completion of the one-month testing period. Because only one testing period shall be required in this Verification Testing Plan, the FTO shall specify the primary permeate flux at which the equipment is to be verified.

Concentrate streams and other waste streams generated by the membrane equipment must be fully characterized during Task 1 testing. The FTO shall fully describe and provide general characterization of the waste streams that are generated by the RO or NF membrane treatment system in the FOD, including pH, temperature, conductivity, TDS, alkalinity, turbidity, TSS, TOC and disinfectant residual. The FTO shall also discuss the applicable potential waste stream disposal issues in the FOD, including disposal to the sewer or receiving waters.

Testing of additional operational conditions may be included in the Verification Testing Program at the discretion of the Manufacturer and their designated FTO. Testing of alternate operational conditions shall be performed by including additional one-month testing period beyond the one-month testing period required by the Verification Testing Program. Additional testing periods may be included to demonstrate membrane performance at different operational conditions or under different feedwater quality conditions. The FTO on behalf of the Manufacturer shall perform testing with as many different water quality conditions as desired for verification status.

This NSF Membrane Verification Testing Plan has been written with the aim to balance the costs of verification with the benefits of testing the RO or NF process over a wide range of operating conditions. Given that it may take more than one month to observe a significant specific flux decline in high-pressure membrane systems as RO or NF, examination under a wide range of operating conditions would be prohibitively expensive for the membrane Manufacturer. Therefore, this Verification Testing Plan requires that one set of operating conditions be tested during the one-month testing period. It shall be furthermore understood that beyond the single set of verification operating conditions, membrane operation that occurs at a lower flux, a lower recovery, or a higher cross-flow velocity shall also constitute a verifiable condition.

7.4 Analytical Schedule

7.4.1 Operational Data Collection

Measurement of membrane performance parameters shall be monitored a minimum of 2 times per day, as indicated in Table 3. Monitoring shall be performed for each stage in the RO or NF system. Temperature measurements shall be made on a daily basis in order to provide data for temperature correction of specific flux and for reporting of solute rejection (addressed in Task 3).

In an attempt to calculate costs for operation of membrane equipment, power costs for operation of the membrane equipment shall also be closely monitored and recorded by the FTO during the one-month testing period, as indicated in Table 3. Furthermore, the costs of chemical addition shall be estimated by measurement of chemical usage through recording the day tank concentration, daily volume consumption and unit cost of chemicals.

7.4.2 Feedwater Quality Limitations

The characteristics of feedwaters used during the one-month testing period (and any additional testing periods) shall be explicitly reported with the compiled results from membrane flux, specific flux and recovery monitoring. Accurate reporting of such feedwater characteristics as pH, temperature, conductivity, TDS, alkalinity, turbidity, TSS, silica, TOC concentration and SDI is critical for the Verification Testing Program, as these parameters may substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions. The TDS concentrations in the feedwater, permeate and concentrate streams shall be used to calculate the osmotic pressure gradient (Equation 4.4) across the membrane on a daily basis. Osmotic pressure gradient value shall then be used for calculation of net driving pressure and specific flux on a daily basis. Specific monitoring requirements for feedwater quality shall be stipulated in Task 3.

7.5 Evaluation Criteria and Minimum Reporting Requirements

- General operational performance
  - ⇒ Graph of specific flux normalized to 20 °C or 25 °C (Equation 4.5) vs. time over the one-month testing period. Graphs showing time-dependent change of experimental parameters will be defined as temporal profiles. One temporal profile graph of specific flux shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.

- ⇒ Temporal profile of net driving pressure normalized to 20 °C or 25 °C (Equation 4.3) over the one-month testing period. One temporal profile graph shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.
- ⇒ Temporal profile of water recovery (Equation 4.6) over the one-month testing period. One temporal profile graph shall be provided for each set of operational conditions and/or water qualities evaluated.
- ⇒ Temporal profile of the concentrate flow and other waste stream flows produced during the one-month testing period.

- Power consumption
  - ⇒ Provide table of horsepower requirements, motor efficiency and consumed amperage for the testing period(s), as measured for each set of operational conditions.
- Concentrate stream characterization
  - ⇒ Provide table of concentrate stream quality parameters measured during the one-month testing period.

8.0 TASK 2: CLEANING EFFICIENCY

8.1 Introduction

During and following the test runs of Task 1, the membrane equipment may require chemical cleaning to restore membrane productivity. At a minimum, one cleaning shall be performed at the conclusion of the one-month period of required testing. In the case that the membrane does not fully reach termination criteria as specified by the Manufacturer in Task 1, chemical cleaning shall be performed after the one-month testing period. Measurement of membrane performance parameters at one set of operational conditions shall be made before and after cleaning.

8.2 Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning for restoring the specific flux of the membrane system. Evaluation of the chemical cleaning procedure will be useful in confirming that standard Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity. Furthermore, such testing may determine if the chemical cleaning procedure degrades the membrane in terms of its rejection capabilities for inorganic chemical contaminants. Cleaning chemicals and cleaning routines shall be adopted from the recommendations of the Manufacturer; this task is considered a "proof of concept" effort, not an optimization effort. It should be noted that selection of a chemical cleaning procedure is typically dependent upon the specific feedwater quality. The testing plan should permit evaluation of cleaning solutions that are considered optimal for the selected feedwaters. If the Manufacturer determines that a pre-selected cleaning formulation is not effective, the testing plan should allow the Manufacturer to modify it.

8.3 Work Plan

The membrane systems may experience specific flux decline during the membrane test runs conducted for Task 1. At the conclusion of the one-month testing period, these membranes shall be utilized for the cleaning assessments. No additional experiments shall be required to produce specific flux decline such that chemical cleaning evaluations will be performed. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the initial conditions of specific flux, recovery and inorganics rejection capabilities shall be tested.

The Manufacturer and their designated FTO shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- quantities and costs of cleaning chemicals
- hydraulic conditions of cleaning
- time duration of each cleaning step
- initial and final temperatures of chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed
- recommended methods and considerations for disposal of residual cleaning waste

In addition, detailed procedures describing the methods for pH neutralization of the used acid or alkaline cleaning solutions should be provided along with information on the proper disposal method for regulated chemicals. A description of all cleaning equipment and its operation shall be included in the FOD prepared by the FTO.

8.4 Analytical Schedule

8.4.1 Operational Data Collection

Flow rates, pressures, recovery, and temperature data shall be collected during the cleaning procedure if possible and shall be recorded immediately preceding system shutdown. At the conclusion of each chemical cleaning event and immediately upon return to membrane operation, the initial operating conditions of net driving pressure, flow rate, recovery, and temperature shall be recorded and the specific flux calculated.

The efficacy of chemical cleaning shall be evaluated by the recovery of temperature-adjusted specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficacy achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible loss of specific flux and projections for usable membrane life. Analysis of feedwater and permeate quality in subsequent runs shall also be used to evaluate any loss in membrane rejection capabilities caused by chemical cleaning.

Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1) The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (J_{tmf}) and the initial specific flux (J_{tmi}) measured for the subsequent filtration run:

$$\%\,\text{Recovery of Specific Flux} = 100 \cdot \left[1 - \frac{J_{tm_f}}{J_{tm_i}}\right] \qquad (8.1)$$

where: J_{tmf} = Final Specific flux (gfd/psi, L/(h-m^2)/bar) at end of the previous run
J_{tmi} = Initial Specific flux (gfd/psi, L/(h-m^2)/bar) at the beginning of the current run.

2) The loss of specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (J_{tmi}) divided by the original specific flux measured at the initiation of operation for the first filtration run in a series (J_{tmio}):

$$\%\,\text{Loss of Original Specific Flux} = 100 \cdot \left[1 - \frac{J_{tm_i}}{J_{tm_{io}}}\right] \qquad (8.2)$$

where: J_{tmio} = Original Specific flux (gfd/psi, L/(h-m^2)/bar) measured at the initiation of membrane testing.

8.4.2 Sampling

The temperature, pH, conductivity, TDS, TOC and turbidity of each cleaning solution shall be measured and recorded during various periods of the chemical cleaning procedure. In addition, in the case that the cleaning solution employs an oxidant, such as chlorine, the concentration of the oxidant both before and at the end of the cleaning should be measured. Notes recording the visual observations (color, degree of suspended matter present) shall also be provided by the FTO. No other water quality sampling shall be required.

8.5 Evaluation Criteria and Minimum Reporting Requirements

The minimum reporting requirements shall include presentation of the following results:

- Specific flux recovery

⇒ Provide table of post cleaning specific flux recoveries during the one-month period of operation

- Cleaning efficiency

⇒ Provide table of cleaning efficiency indicators described above for chemical cleaning procedures performed during the one-month period of operation

- Assessment of irreversible loss of specific flux and estimation of usable membrane life for costing purposes.

9.0 TASK 3: FEEDWATER AND TREATED WATER QUALITY MONITORING

9.1 Introduction

The water quality data for the feedwater, the membrane permeate and concentrate streams shall be collected during the membrane test runs conducted as part of Task 1. No additional test runs shall be performed for Task 3 to acquire data on feedwater and treated water quality. The requirements for monitoring of water quality parameters in the feedwater, permeate and concentrate streams shall be clearly specified by the FTO in the FOD according to the objectives of the Verification Testing program and the Statement of Performance Capabilities. The specific water quality goals and the target removal goals for the membrane equipment shall also be recorded in the FOD. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing in this Testing Plan is provided in Table 4 in the Analytical Schedule section below. A list of the potential water quality parameters for additional monitoring is provided in Table 5 for the feedwater, the membrane permeate and concentrate streams. The actual water quality parameters selected for testing and monitoring during equipment Verification Testing shall be explicitly stipulated by the FTO in the FOD.

9.2 Experimental Objectives

The objective of this task is to assess the ability of the membrane equipment to demonstrate the treatment and/or rejection capabilities indicated in the FOD Statement of Performance Capabilities. Mass balances shall be performed as part of Task 3 in order to evaluate the concentration of rejected species at the membrane surface during membrane operation. Calculation of the recovery limitation caused by limiting salts will be performed to determine the impact of feedwater quality on membrane operation. Statistical analysis, as described in the "Protocol for Equipment Verification Testing of Removal of Inorganic Constituents" (Section 4.5: Recording Statistical Uncertainty) is only required for those water quality parameters that shall be monitored on a weekly basis during each Verification Testing period.

9.3 Work Plan

The Manufacturer through their designated FTO shall identify the equipment rejection capabilities for selected inorganic chemical contaminants in the Statement of Performance Capabilities provided in the FOD. The Statement of Performance Capabilities shall clearly establish the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. For each Statement of Performance Capabilities proposed by the FTO, the following information shall be provided: percent removal of the targeted inorganic constituent, rate of treated water production (i.e., flux); recovery; feedwater quality regarding pertinent water quality parameters; temperature; concentration of target inorganic constituent; and other pertinent water quality and operational conditions. Two examples of acceptable Statements of Performance Capabilities are provided in Table 1. The Statement of Performance Capabilities prepared by the Manufacturer and their designated FTO shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater, as indicated by examples in Table 1.

Monitoring of water quality parameters in the feedwater, permeate and concentrate water streams shall allow calculation of percent rejection of the measured parameters and targeted inorganic chemical contaminants for the specific operational conditions evaluated. Estimation of the percent rejection of selected inorganic water quality parameters shall be based upon the equation for solute rejection provided in the section titled Definition of Operational Parameters, Equation 4.8.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. Analysis of the remaining water quality parameters shall be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters are identified in Tables 4 and 5. Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures. A number of the analytical methods utilized in this study for on-site monitoring of feedwater and permeate water qualities are further described in Task 5, Quality Assurance Project Plan.

For the water quality parameters requiring analysis at a state-certified or third party- or EPA-accredited laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited laboratory. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

It should be noted that the membrane equipment participating in the Verification Testing Program for inorganics removal may be capable of achieving multiple water treatment objectives. Although this Testing Plan is oriented towards removal of inorganic chemical contaminants, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

9.4 Analytical Schedule

9.4.1 Feedwater, Permeate and Concentrate Characterization

During the one-month testing period, the feedwater, permeate and concentrate water streams shall be characterized at a single set of operating conditions indicated in the Statement of Performance Capabilities. The minimum water quality monitoring requirements for this Verification Testing plan are provided in Table 4.

Table 4: Minimum Required Water Quality Sampling

Parameter	Sampling Frequency	Test Stream to be Sampled	Standard Method	EPA Method
pH	1/Day	Feed, Perm.	4500- H+ B	150.1 150.2
Temperature	2/Day	Feed	2550	
Conductivity	2/Day	Feed, Perm., Conc.	2510 B	120.1
TDS	1/Day*	Feed, Perm., Conc.	2540 C	
Alkalinity	1/Month	Feed, Perm., Conc.	2320 B	
Langlier Saturation Index (LSI)	1/Month	Feed, Perm., Conc.		
Turbidity	1/Month	Feed, Perm., Conc.	2130 B Method 2	180.1
TSS	1/Month	Feed, Perm., Conc.	4500-NH_3 G 2540 D	
Silica (total and dissolved)	1/Month	Feed, Perm., Conc.	3500 Si 4500-Si D 4500-Si E 4500-Si F 3120 B	200.7
TOC	1/Month	Feed, Perm., Conc.	5310 C	
Silt Density Index (SDI)	1/Month	Feed	ASTM D4189-95	
Selected Inorganic Constituents (see Table 5)	1/Week	Feed, Perm., Conc.		

*May be collected 1/week to establish a site-specific conductivity vs. TDS curve to allow conversion of conductivity to TDS for calculation of osmotic pressure gradient daily.

In addition, the FTO (on behalf of the Manufacturer) shall indicate in the FOD the specific target inorganic chemical contaminants that shall be monitored in the Verification Testing Program per the Statement of Performance Capabilities. A list of the potential inorganic chemical contaminants that may be included in this Verification Testing program is included in Table 5. The recommended monitoring frequency for these inorganic chemical contaminants shall be a minimum of once per week.

9.4.2 Water Quality Sample Collection

Water quality data shall be collected at the specified intervals during each testing period. The minimum monitoring frequency for the minimum required water quality parameters is provided in Table 4. A minimum monitoring frequency of once per week shall be adopted for additional inorganic chemical contaminants to be included in the Verification Testing Program. At the discretion of the Manufacturer and the designated FTO, the water quality sampling program may be expanded to include any number of water quality parameters and an increased frequency of water quality parameter sampling. Sample collection frequency and protocol shall be defined explicitly by the FTO in the FOD. To the extent possible, analyses for inorganic water quality parameters shall be performed on water sample aliquots obtained simultaneously from the same sampling location, in order to ensure the maximum degree of comparability between water quality analytes.

Table 5: List of Inorganic Chemical Contaminants for Verification Testing

Parameter	Standard Method	EPA Method
Aluminum	3500 Al	200.7, 200.8, 200.9
Barium	3500 Ba	200.7, 200.8
Cadmium	3500 Cd	200.7, 200.8, 200.9
Calcium	3500 Ca	200.7
Chloride	4500 Cl^-	300.0
Chromium	3500 Cr	200.7, 200.8, 200.9
Fluoride	4500 F^-	300.0
Iron	3500 Fe	200.7, 200.9
Manganese	3500 Mn	200.7, 200.8, 200.9
Magnesium	3500 Mg	200.7
Nitrate	4500 NO_3^{-2}	300.0, 353.2
Nitrite	4500 NO_2^{-2}	300.0, 353.2
Ortho-Phosphate		365.1, 300.0
Sodium	3500 Na B	200.7
Strontium	3500 Sr	200.7
Sulfate	4500 SO_4^{-2}	300.0, 375.2
Other Inorganic Chemical Contaminants	TBD*	
Optional:		
UV absorbance	5910 B	
Total Trihalomethanes		502.2, 524.2, 551
Haloacetic Acids		552.1
Total Coliform Bacteria	9221 B or Colilert	300.0 B
Heterotrophic Plate Count Bacteria	9215 B	300.0 B

* TBD - to be determined

The TDS concentrations in the feedwater, permeate and concentrate streams shall be used to calculate the ionic strength of the feedwater and concentrate streams, as well as osmotic pressure gradient across the membrane on a daily basis. Osmotic pressure gradient value shall then be used for calculation of net driving pressure and specific flux on a daily basis. Mass balances for specified water quality parameters shall also be calculated at a frequency (minimum of once weekly) designated by the FTO. Calculation of the potential for recovery limitation based upon limiting salt concentrations shall also be performed at a frequency (minimum of once weekly) designated by the FTO

9.5 Evaluation Criteria and Minimum Reporting Requirements

- Percent removal of inorganic chemical constituents

⇒ Provide temporal plot of concentrations of target inorganic constituents and TDS in the feedwater, permeate and concentrate water streams over the one-month period of operation. Relevant inorganic constituents for monitoring shall be specified by the FTO on behalf of the Manufacturer in the FOD.

⇒ Provide table with weekly values of percent removal of target inorganic constituents and other pertinent water quality parameters for the one-month period of operation. The equation shown in the section titled Definition of Operational Parameters shall be used to determine percent removal of all pertinent water quality parameters for Verification Testing by the FTO and Manufacturer.

⇒ Conduct mass balances through the membrane testing system for specific water quality constituents (minimum of once weekly) as identified by the FTO in the FOD. The mass balance equation presented in the section titled Definition of Operational Parameters shall be used to the mass of concentration of inorganic constituents in different water streams.

⇒ Calculate limiting salt concentrations (via solubility product calculation Equation 4.11) for specific water quality constituents (minimum of once weekly) as identified by the FTO in the FOD. The equation for solubility product calculation as presented in the section titled Definition of Operational Parameters (Equation 4.11) shall be used to compare with standard Solubility Product values to determine if the salt concentration is posing a limitation to operational system recovery.

- Individual water quality and removal goals specified by the Manufacturer

⇒ Provide feed, permeate and concentrate concentrations of any measured water quality parameters in tabular form for the one-month period of operation.

- Removal of Total Suspended Solids and Turbidity

⇒ Plot temporal graph of feedwater and permeate measurements for total suspended solids during the one-month period of operation.

⇒ Plot temporal graph of feedwater and permeate turbidity measurements during the one-month period of operation.

10.0 TASK 4: DATA HANDLING PROTOCOL

10.1 Introduction

The data management system used in the Verification Testing program shall involve the use of computer spreadsheets and manual (or on-line) recording of operational parameters for the membrane equipment on a daily basis.

10.2 Experimental Objectives

The objectives of this task are: 1) to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable data to NSF for verification purposes, and 2) to develop a statistical analysis of the data, as described in the NSF document "Protocol For Equipment Verification Testing of Removal of Inorganic Constituents."

10.3 Work Plan

The following protocol has been developed for data handling and data verification by the FTO. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of membrane equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the FTO at least once per week during the one-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the membrane equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g., each membrane test run) shall be assigned a run number that will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

As available, electronic data storage and retrieval capabilities shall be employed in order to maximize data collection and minimize labor hours required for monitoring. The guidelines for use of data-loggers, lap-top computers, data acquisition systems etc., shall be detailed by the FTO in the FOD.

11.0 TASK 5: QUALITY ASSURANCE PROJECT PLAN

11.1 Introduction

Quality assurance and quality control of the operation of the membrane equipment and the measured water quality parameters shall be maintained during the Verification Testing program. A Quality Assurance Project Plan detailing the QA/QC procedures to be followed during Verification Testing shall be provided by the FTO as part of the FOD.

11.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

11.3 Work Plan

Equipment flowrates and associated signals should be documented and recorded on a routine basis. A routine daily walk through during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to confirm that any chemicals are being fed at the defined flowrate into a flowstream that is operating at the expected flowrate, such that the chemical concentrations are correct. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e. flowrate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

11.3.1 Daily QA/QC Verifications:

- Chemical feed pump flowrates (verified volumetrically over a specific time period)
- Flow rates to on-line analytical equipment (e.g., pH meter, conductivity meter, turbidimeter), if any (verified volumetrically over a specific time period).

11.3.2 Monthly QA/QC Verifications:

- In-line flowmeters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings);
- On-line pH meters, conductivity meters, turbidimeters etc. (clean out reservoirs and re-calibrate, if employed)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter);
- Tubing (verify good condition of all tubing and connections; replace if necessary)

11.4 Analytical Methods and Sample Collection

The analytical methods utilized in this Equipment Verification Testing Plan for on-site monitoring of feedwater, permeate and concentrate water quality are described in the section below. Use of either bench-top or on-line field analytical equipment will be acceptable for the Verification Testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

11.4.1 pH

Analyses for pH shall be performed according to Standard Method 4500-H^+. A two-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual.

11.4.2 Conductivity

Analyses for conductivity shall be performed according to Standard Method 2510 B. A three-point calibration of the conductivity meter used in Verification Testing shall be performed once per day when the instrument is in use. Certified conductivity solutions in the expected range shall be used. The probe shall be stored in the appropriate solution defined in the instrument manual.

11.4.3 Turbidity

Turbidity analyses shall be performed according to Standard Method 2130 with either an on-line or bench-top turbidimeter. During each pilot testing period, the on-line and bench-top turbidimeters shall be left on continuously. Once each turbidity measurement is complete, the unit shall be switched back to its lowest setting. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The FTO shall be required to document any problems experienced with the turbidity monitoring instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

On-line Turbidimeters: On-line turbidimeters may be used for measurement of turbidity during Verification Testing, and must be calibrated as specified in the instrument manufacturer's operation and maintenance manual. It will be necessary to periodically verify the on-line readings using a bench-top turbidimeter; although the mechanism of analysis is not identical between the two instruments, the readings should be comparable. Should the comparison suggest inaccurate readings, then all on-line turbidimeters should be re-calibrated. In addition to calibration, periodic cleaning of the lens should be conducted using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow shall also be performed using a volumetric measurement. Instrument bulbs shall be replaced on an as-needed basis. It should also be verified that the LED read-out matches the data recorded by the data acquisition system, if the latter is employed.

Bench-Top Turbidimeters: Grab samples of feedwater and oxidized/disinfected water may be analyzed using a bench-top turbidimeter. Readings from this instrument shall serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of pilot plant operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 5.0 Nephlometric Turbidity Units (NTU). Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to re-calibrate when more than one turbidity range is used.

The method for collecting grab samples shall be performed according to the following protocol: 1) running a slow, steady stream from the sample tap, 2) triple-rinsing a dedicated sample beaker in this stream, 3) allowing the sample to flow down the side of the beaker to minimize bubble entrainment, 4) double-rinsing the sample vial with the sample, 5) carefully pouring from the beaker down the side of the sample vial, 6) wiping the sample vial clean, 7) inserting the sample vial into the turbidimeter, and 8) recording the measured turbidity. For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion in a warm water bath for approximately 30 seconds.

11.4.4 Analysis for Inorganic Chemical Contaminants

Methods to be employed for analysis of specific analytical parameters shall be explicitly identified by the FTO in the FOD. The methods selected for analysis of all inorganic constituents shall comply with those described in the most recent edition of Standard Methods or should be considered a comparable EPA Method.

12.0 OPERATION AND MAINTENANCE

The following are recommendations for criteria to be included in Operation and Maintenance (O&M) Manuals for RO/NF membrane package plants that are designed to achieve removal of inorganic chemical constituents. Descriptions of the membrane equipment unit process shall be developed by the FTO on behalf of the Manufacturer and included in the FOD. Appropriate parameters for system description shall include but not be limited to the following elements: standard design criteria, membrane element and process characteristics, pre-treatment requirements and post-treatment concerns. An overview of the pertinent membrane plant design information that may be required for the FOD is provided in Table 6. A list of relevant membrane element characteristics is provided in Table 7. Table 8 provides an overview of the chemical addition details that are pertinent to operation and design of pretreatment systems ahead of RO/NF. The following sections provide lists of maintenance and operations criteria that may be helpful for development of O & M Manuals for RO membrane systems.

12.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves, including detailed information on the valve configuration for cross-flow operation
- pressure gauges
- flow meters
- air compressors
- chemical feeder systems
- mixers
- motors
- instruments, such as streaming current monitors or turbidimeters
- water meters, if provided

The Manufacturer shall provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- in-line static mixers
- tubing and hoses

12.2 Operation

The Manufacturer should provide readily understood recommendations for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are the following issues:

Membrane Filtration:

- control of feed flow to the membrane system and individual stages
- measurement of inlet/outlet pressures and permeate flows
- measurement of transmembrane pressure changes during membrane test run
- feed flow control in response to temperature changes
- measurement/calculation of cross-flow velocity

Chemical cleaning:

- selection of proper chemical washing sequence
- proper procedures for dilution of chemicals
- monitoring of pH through chemical cleaning cycle
- rinsing of membrane system following chemical clean
- return of membrane system to service

Chemical feeders (in the case that chemical pretreatment is applied):
- calibration check on flow meters and dosing pumps
- settings and adjustments -- how they should be made
- dilution of chemicals -- proper procedures

Intermittent Operation:
- proper procedures for system shut-down and start-up
- safety checks of chemical concentrations prior to system shut-down
- safety checks of potential contaminant concentrations prior to system shut-down and start-up
- proper procedures for rinsing and disinfection of system following shut-down

Monitoring and Sampling Procedures:
- observation of feedwater or pretreated water turbidity
- observation of transmembrane pressure increase
- proper monitoring procedures for measurement of permeate conductivity
- proper safety procedures

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:
- no raw water (feedwater) flow to plant
- can't control rate of flow of water through package plant
- poor permeate quality
- failed test for membrane integrity
- low pressure at feedwater pump
- automatic operation (if provided) not functioning
- transmembrane pressure builds up excessively rapidly
- reduced permeate flux
- reduced percent solute rejection
- machine will not start and "Power On" indicator off
- machine will not start and "Power On" indicator on
- pump cavitation
- valve stuck or won't operate
- no electric power
- no chemical feed for pH adjustment
- no antiscalant addition

12.3 Operability

The following are recommendations regarding operability aspects of package plants that are designed to achieve removal of inorganic chemical contaminants. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program.

During Verification Testing and during compilation of historical package plant operating data, attention shall be given to package plant operability aspects. Among the factors that should be considered are:

- fluctuation of flow rates and pressures through membrane unit -- the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- presence of devices to aid the operator with flow control adjustment and chemical dosage selection:

⇒ are continuous turbidimeters provided for monitoring of feedwater and permeate turbidity?

- continuous particle counter provided for monitoring of membrane permeate?
- does plant have multiple feed points for chemicals:

⇒ for pH adjustment?

⇒ for antiscalant addition?

- is transmembrane pressure measurement provided?
- is rate of flow of raw water measured?
- are chemical feeds paced with raw water flow?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Tasks 1 & 2 of the Verification Testing Plan.

Table 6: Membrane Plant Design Criteria Reporting Items

Parameter	**Value**
Number of Stages	
Number Pressure Vessels in Stage 1	
Number Pressure Vessels in Stage 2	
Number Membrane Elements per Pressure Vessel	
Recovery per Stage (%)	
Recovery for System (%)	
Design Flux (gfd)	
Initial Specific Flux (gfd/psi) at 20 °C or at 25 °C	
Maximum Flow Rate to an Element (gpm)	
Minimum Flow Rate to an Element (gpm)	
Pressure Loss per Element (psi)	
Pressure Loss in Stage Entrance and Exit (psi)	
Feed Stream TDS (mg/L)	
TDS Rejection (%)	
Rejection of Specific Inorganic Constituent (%)	

Table 7: Membrane Element Characteristics

Parameter	**Value**
Membrane Manufacturer	
Membrane Element Model Number	
Size of Element Used in Study (e.g., 4”x40”)	
Active Membrane Surface Area per Element (ft^2, m^2)	
Active Surface Area of Equivalent 8”x40” Element (ft^2, m^2)	
Sales Price for an Equivalent 8”x40” Element ($)	
Molecular Weight Cut-Off (Daltons)	
Membrane Material Construction	
Membrane Hydrophobicity	Hydrophilic/Hydrophobic
Reported Membrane Charge	Negative/Neutral/Positive
Spacer Thickness (ft)	
Scroll Width (ft)	
Design Pressure (psi)	
Design Flux at Design Pressure (gfd)	
Variability of Design Flux (%)	
Design Specific Flux (gfd/psi) at 20 °C at 25 °C	
Standard Testing Recovery (%)	
Standard Testing pH	
Standard Testing Temperature (°C)	
Design Cross-Flow Velocity (ft/s)	
Maximum Flow Rate to an Element (gpm)	
Minimum Flow Rate to an Element (gpm)	
Required Feed Flow to Permeate Flow Ratio	
Maximum Element Recovery (%)	
Rejection of Reference Solute and Conditions of Test (e.g., Solute type and concentration)	
Variability of Rejection of Reference Solute (%)	
Acceptable Range of Operating Pressures (psi, bar)	
Acceptable Range of Operating pH Values	
Typical Pressure Drop across a Single Element (psi)	
Maximum Permissible SDI	
Maximum Permissible Turbidity	
Chlorine/Oxidant Tolerance	
Suggested Cleaning Procedures	

Table 8: Pretreatment Processes Used Ahead of Reverse Osmosis or Nanofiltration

Parameter	**Value**
Pre-Filter Exclusion Size (μm)	
Type of Acid used	
Acid Concentration	
Volume Acid added (mL) per L of Feedwater	
Type of Scale Inhibitor Used	
Scale Inhibitor Concentration	
Volume Scale Inhibitor added (mL) per L of Feedwater	
Type of Coagulant used	
Coagulant Dose (mg/L)	
Type of Polymer used during Coagulation	
Polymer Dose (mg/L)	

13.0 REFERENCES

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